



## NASA SBIR 2022 Phase I Solicitation

### Z13.01 Active and Passive Dust Mitigation Surfaces

Lead Center: KSC

Participating Center(s): JSC, LaRC

#### Scope Title

Advanced Technologies for Active Dust Mitigation

#### Scope Description

Proposals are sought that use unique methods that may require power, gases, mechanisms, vibrations, or other means necessary to keep vital surfaces clean under space conditions while not interfering with the form/fit/function of the surface they are acting upon. Self-cleaning surfaces that require minimal effort by astronauts are highly desired. Proposals that address removal of dust on passive (low surface energy) dust mitigation surfaces are also sought. Proposers are expected to show an in-depth understanding of the current state-of-the-art (SOA) and quantitatively describe improvements over relevant SOA technologies that substantiate investment in the new technology. Proposers must also quantitatively explain the operational benefit of the new technology from the perspective of improving or enabling mission potential. Some examples of active dust mitigation technologies include but are not limited to:

- Brushing: A self-cleaning brush to mechanically remove dust from surfaces. The brush can be mechanically operated using power or can be temperature activated, such as shape memory alloys.
- Electrostatic removal: Methods to use direct-current (DC) electric fields to remove dust from surfaces, either internal to the surface (embedded) or external using a removed high-voltage source.
- Vacuum: Methods to remove particles from surfaces using suction of gases.
- Jets: High-velocity gas jet that blows dust particles from surfaces.
- Spinning surfaces: Surface rotates in a manner that does not allow collection of dust on it.
- Vibrational surfaces: Vibrating surface bounces the particles off of the surface.
- Electrodynamic removal: The surface contains embedded electrodes with varying high-voltage signals applied to lift and transport dust off of the surface.

Proposals are highly sought in which the active dust mitigation strategy could be combined with the SOA of passive dust mitigation technologies. For example, passive dust mitigation strategies include:

- Electrostatic discharge (ESD) coatings and films: Statically dissipative coatings are less likely to accumulate

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charge, and hence dust, in dry environments.

- Superhydrophobic coatings: Materials with a very high contact angle can lower the adhesion of water-based contaminants, not allowing the capillary forces to take hold.
- EVA- and robotic-compatible dustproof electrical, fluid, and gas connectors.
- Lotus leaf coating: Microscopic nanostructures used to limit the van der Waals force of adhesion.
- Peel-away coating: Removable surface coatings.
- Gradient surfaces that direct dust adhesion away from vital surfaces.

Strong proposals are those that identify the active dust removal strategy in coordination with other dust prevention and removal methods as listed above. Strong proposals will also include a brief description of an infusion plan for a flight demonstration using Phase II funding.

### **Expected TRL or TRL Range at completion of the Project**

3 to 6

### **Primary Technology Taxonomy**

#### **Level 1**

TX 12 Materials, Structures, Mechanical Systems, and Manufacturing

#### **Level 2**

TX 12.3 Mechanical Systems

### **Desired Deliverables of Phase I and Phase II**

- Hardware
- Prototype

### **Desired Deliverables Description**

At the end of the Phase I research period, it is expected that a material or technology will be identified and initial characterization results collected. Initial characterization should indicate whether further development of the technology would be scalable and should exhibit a dramatic reduction (>90% relative to full dust loading of a reference material surface such as an aerospace aluminum alloy or polymeric film surface such as Kapton® or Teflon®) in particulate adhesion for microparticles, specifically those described as lunar dust simulant, with diameters <50 Åµm. At the end of Phase II, it is expected that promising technologies will have been demonstrated through relevant environmental test conditions. The materials or technology should be demonstrated to be scalable to quantities sufficient for application beyond laboratory research requirements, i.e., at kilogram or greater quantities for materials or a similar measure for a passive technology. Cost analysis for scaling to mission-requirements level, as will be elucidated through the course of this research, will also be required.

If a Phase II is awarded, further development of the technology shall be required, including a prototype delivered to NASA at the end of the 2-year project with a goal of achieving Technology Readiness Level (TRL) 6. A prototype of the new technology must be provided that shows the feasibility of the dust removal method. The technology must be demonstrated in a laboratory environment removing and/or keeping dust from adhering to a surface. The mass, power, volume, and potential costs associated with the implementation of this technology must be addressed. A well-developed infusion plan resulting in a flight demonstration must also be provided.

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## State of the Art and Critical Gaps

All new technologies for Active Dust Mitigation must include a full knowledge base of the SOA, and proposals that advance the current SOA are encouraged. For example, NASA has developed the Electrodynamic Dust Shield (EDS), which lifts and transports dust off of surfaces with embedded electrodes within a dielectric. A brief but not complete introduction to the technology can be found in the references provided.

The EDS can be incorporated into a variety of configurations addressing many of NASA's needs. However, several potential improvements and technologies that can further the development of the EDS technology are also highly sought within this call. Some potential advances include:

- High dielectric breakdown strength for both glues/epoxies and the coating material: The efficiency of dust removal for the EDS is limited to the amount of voltage that can be applied to the electrodes. The electrical breakdown occurs across the 2D surface because of the dielectric strength limitation of the adhering material as well as the coating material.
- Flexible transparent surfaces with high current capabilities: The optically transparent version of the EDS uses indium tin oxide (ITO) as the main conductive medium for its electrode. Although the EDS is not a high-current DC device, the displacement current ( $I \sim dV/dt$ ) can be quite high. Transparent electrode materials are sought that can replace ITO as the conductive medium that have higher current capabilities and lower overall resistivities. Another shortcoming of ITO is its range of flexibility. Many ITO coatings cannot be bent past a certain degree and are not compatible with numerous folds and bends.
- Electrical attachment: Most EDS systems have issues with the electrical connections between the high-voltage power supply (HVPS) and the electrodes. Any possibility of arcing and/or sparking as a result of slight differences between the wiring from one material configuration to another is exacerbated when powered with EDS waveforms. Proposals are highly sought that address this key issue for attaching high-voltage wires to electrodes embedded in an EDS circuit. EDS circuit electrodes are made using a variety of materials such as copper (wires or vapor deposited), ITO, silver paint wires, carbon nanotube (CNT), and graphene, to name a few. Likewise, these and other electrodes are usually resting on or embedded into a substrate such as glass, polyimide (Kapton®), clothing fibers, polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE), polyamide (nylon), poly(methyl methacrylate) (PMMA, e.g., acrylic, LUCITE®), and other surfaces.
- Minimizing electromagnetic interference (EMI): Most EDS designs can generate electrical noise that would be disadvantageous if incorporated into a system. Methods to reduce electrical noise and EMI are highly sought.
- Safety: With all EDS systems, the use of high voltage requires safety measures for the astronaut and the equipment. Methods to improve the safety and reliability of the EDS in the case of arcing is highly sought.
- Smart EDS technology: As with all dust mitigation technologies, methods to include adaptive techniques are highly sought. The system should be able to check its environment to see if dust clearing is necessary and, if it is, apply power to the system until the cleanliness requirements are met for reliability and power minimization.

Other active systems also require maturation. Critical gaps in these areas include:

- Effective and scratch-resistant brushing techniques. Apollo astronauts used brushes that are largely ineffective for large surface areas and tend to scratch sensitive equipment, such as astronaut visors.
- Gaseous removal of dust on the lunar surface may contaminate other sensitive equipment. A better approach to gaseous or fluidized removal of dust is needed.
- Simple mechanical or vibrational dust mitigation implementations are required. As particles move, they also become highly electrostatically charged, further causing dust adhesion.

## Relevance / Science Traceability

Adhesion of granular materials and the technologies that address mitigation through this subtopic will advance the state of knowledge of this difficult research subject. The interplay between the surface's energy, chemistry, and mechanical properties and the particle's surface is a fascinating but not well-

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understood science. This call will not only extend exploration missions on the lunar surface but will enable exploration missions that would not have been possible. For example, every mechanical seal was compromised on the Apollo missions over 3 days due to exposure to the dust. Research that elucidates this complex behavior toward lunar dust adhesion could be vital for realization of a sustained lunar presence, and although our understanding of the lunar environments has continued to improve, materials and technologies that arise from this research will expand our survival on dusty surfaces in space.

Ideally, a universal lunar simulant will be identified by NASA and should be used for performance verification of developed technologies. If no universal simulant is identified, the specific properties of the utilized particulate material should be identified and related to known properties of lunar dust.

## References:

1. Calle, C. I., et al.: Active dust control and mitigation technology for lunar and Martian exploration. *Acta Astronautica* 69.11-12 (2011): 1082-1088.
2. Calle, C. I., et al.: Particle removal by electrostatic and dielectrophoretic forces for dust control during lunar exploration missions. *Journal of Electrostatics* 67.2-3 (2009): 89-92.
3. Mackey, P. J., et al.: Electrodynamic dust shield for space applications. ASCE Earth & Space Conference, Orlando, Florida, 2016.
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5. Kawamoto, H., and Inoue, H.: Magnetic cleaning device for lunar dust adhering to spacesuits. *Journal of Aerospace Engineering* 25.1 (2011): 139-142.
6. Vangen, S., et al.: International Space Exploration Coordination Group assessment of technology gaps for dust mitigation for the Global Exploration Roadmap. AIAA SPACE 2016. 2016. 5423.
7. Gaier, J., et al.: Evaluation of surface modification as a lunar dust mitigation strategy for thermal control surfaces. 41st International Conference on Environmental Systems. 2011.
8. Wagner, S.: An assessment of dust effects on planetary surface systems to support exploration requirements. 2004.
9. Afshar-Mohajer, N., et al.: Review of dust transport and mitigation technologies in lunar and Martian atmospheres. *Advances in Space Research*, 56(6), Sept. 15, 2015, 1222-1241.
10. Gaier, J.: The effects of lunar dust on EVA systems during the Apollo missions. National Aeronautics and Space Administration, 2005, NASA/TM-213610.
11. Lee, L.-H.: Adhesion and cohesion mechanism of lunar dust on the Moon's surface. *J. Adhes. Sci. Technol.* 1995, 9 (8): 1103-1124.
12. Gaier, J. R., Siamidis, J., Larkin, E. M. G.: Effect of simulated lunar dust on the properties of thermal control surfaces. *J Spacecraft Rockets* 2010, 47 (1): 147-152.
13. Proctor, M. P., Dempsey, P.: Survey of dust issues for lunar seals and the RESOLVE project. 2006, NASA/TM-0010457.
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15. Wohl, C., Belcher, M., Ghose, S., Hopkins, J., Connell, J.: Topographical modification of materials for mitigation of lunar dust adhesion. In 40th Lunar and Planetary Science Conference, The Woodlands, Texas, United States, 2009.
16. Gaier, J. R., Meador, M. A., Rogers, K. J., Sheehy, B. H.: Abrasion of candidate spacesuit fabrics by simulated lunar dust. National Aeronautics and Space Administration, 2009, TM-215800.

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## Scope Title

Advanced Technologies for Passive Dust Mitigation

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## Scope Description

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This call seeks unique research proposals focused on passive approaches, i.e., those that do not require external stimulus, that will minimize the potential impact lunar dust will have on future exploration missions. These approaches may include novel materials and surfaces as well as technologies that require no external input (a self-activating system) while not interfering with the form/fit/function of the surface they are acting upon. Novel materials may include high-performance plastics, metals, ceramics, etc. Surfaces may be homogeneous or heterogeneous (i.e., nonisotropic surface properties resulting in directional dust adhesion control), and rough or smooth with topography imparted by any number of approaches, including, but not limited to: lithography, embossing, roll-to-roll processing, etc. Surfaces can incorporate strategies for mitigation of adhesion contributions from van der Waals interactions, electrostatic forces, and chemically reactive or mechanical interactions. Both the material and surface modification approach must be demonstrated to be scalable and exhibit a dramatic reduction (>90% relative to a reference material surface such as an aerospace aluminum alloy or polymeric film surface such as Kapton® or Teflon®) in particulate adhesion for microparticles, specifically those described as lunar dust simulant, with diameters <50 Åµm.

Strong proposals will seek to demonstrate the efficacy of lunar dust adhesion mitigation and the durability to retain these properties in a simulated environment. Strong proposals will include characterization of the solar reflectivity and infrared (IR) emissivity of the passive approach applied, if applicable. Strong proposals will also include a brief description of an infusion plan for a flight demonstration using Phase II funding.

### **Expected TRL or TRL Range at completion of the Project**

3 to 6

### **Primary Technology Taxonomy**

#### **Level 1**

TX 12 Materials, Structures, Mechanical Systems, and Manufacturing

#### **Level 2**

TX 12.1 Materials

### **Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware

### **Desired Deliverables Description**

At the end of the Phase I research period, it is expected that a material or technology will be identified and initial characterization results collected. Initial characterization should indicate whether further development of the technology would be scalable and should exhibit a dramatic reduction (>90% relative to full dust loading of a reference material surface such as an aerospace aluminum alloy or polymeric film surface such as Kapton® or Teflon®) in particulate adhesion for microparticles, specifically those described as lunar dust simulant, with diameters <50 Åµm. At the end of Phase II, it is expected that promising technologies will have been demonstrated through relevant environmental test conditions. The materials or technology should be demonstrated to be scalable to quantities sufficient for application beyond laboratory research requirements, i.e., at kilogram or greater

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quantities for materials or a similar measure for a passive technology. Cost analysis for scaling to mission-requirements level, as will be elucidated through the course of this research, will also be required.

If a Phase II award is made, further development of the technology shall be required, including a prototype delivered to NASA at the end of the 2-year project with a goal of achieving Technology Readiness Level (TRL) 6. A prototype of the new technology must be provided that shows the feasibility of the dust removal method. The technology must be demonstrated to remove adhered dust or prevent dust adhesion in a laboratory environment simulating some aspects of lunar environmental conditions. Durability of the material surface toward lunar dust abrasion, thermal cycling, and other environmental considerations should also be addressed. The mass, power, volume, and potential costs associated with the implementation of this technology must be addressed. A well-developed infusion plan resulting in a flight demonstration must also be provided.

## **State of the Art and Critical Gaps**

Although a myriad of materials and technologies exist for mitigation of surface contamination for a variety of terrestrial applications, requirements for mitigation of lunar dust adhesion indicate diminished efficacy of many materials. As an example, silicones are used ubiquitously to reduce adhesive interactions and can be effective for contamination prevention across a range of contaminants; however, these relatively soft materials would exhibit deleterious properties in a traditional manifestation arising from particulate embedding due to the sharp edges and hardness of the lunar dust. Likewise, hard traditional ceramic materials have been shown to be beneficial for terrestrial applications; however, triboelectrification of an insulating material would increase adhesion interactions with lunar dust. Beyond these specific lunar dust properties, magnetic interactions, chemical activity, and the velocity of the lunar dust, especially at the lunar terminator, all contribute to adhesion and therefore must be addressed for a material to be expected to perform well in this environment.

Critical technology gaps in passive dust adhesion mitigation include:

- Nanotechnology in permanently shadowed regions.
- Flexible materials with adhesion and abrasion resistance demonstrated across the thermal range of the lunar surface, -170 to 125 Å°C.
- Nonisotropic materials with directional dust adhesion control.
- Dust removal technologies integrated with passive dust mitigation materials.
- Materials and technologies for transition spaces from surface operations to habitat interior spaces.

## **Relevance / Science Traceability**

Adhesion of granular materials and the technologies that address mitigation through this subtopic will advance the state of knowledge of this difficult research subject. The interplay between the surface's energy, chemistry, and mechanical properties and the particle's surface is a fascinating but not well-understood science. This call will not only extend exploration missions on the lunar surface but will enable exploration missions that would not have been possible. For example, every mechanical seal was compromised on the Apollo missions in the course 3 days due to exposure to the dust. Research that elucidates this complex behavior toward lunar dust adhesion could be vital for realization of a sustained lunar presence, and although our understanding of the lunar environments has continued to improve, materials and technologies that arise from this research will expand our survival on dusty surfaces in space.

Ideally, a universal lunar simulant will be identified by NASA and should be used for performance verification of developed technologies. If no universal simulant is identified, the specific properties of the utilized particulate material should be identified and related to known properties of lunar dust.

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